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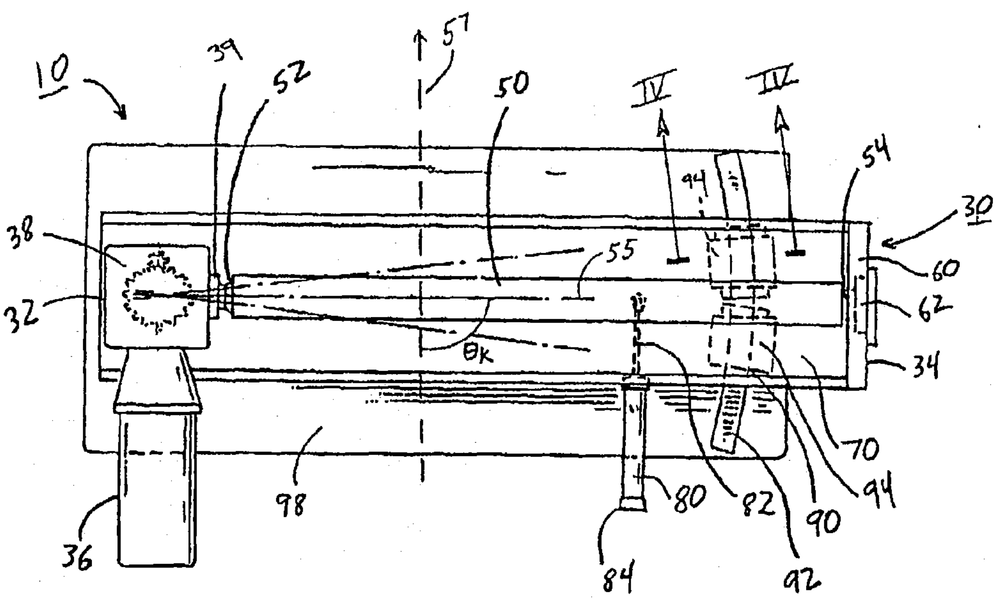
(54) Title: OVERSPEED HELICAL ROTARY KNIFE



(57) Abstract

A method for cutting a moving web (24) comprising adjusting the angle of a rotary knife (50) with respect to a web direction based on web speed, knife speed, and desired product length, allowing the production of products with lengths shorter than the effective circumference of the rotary knife.

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OVERSPEED HELICAL ROTARY KNIFE

FIELD OF THE INVENTION

The invention relates to apparatus used to cut a continuous, moving web of material, specifically helical rotary knives.

BACKGROUND OF THE INVENTION

The cutting of a continuous, moving web of material is often accomplished with a rotary knife. Among the numerous advantages of the rotary knife is its ability to cut at relatively high speeds because the driving mechanism of the knife runs in one continuous direction. A helix is often added to the shape of the knife blade to create a scissors cutting action. The scissors cutting action eliminates the shock load created by cutting the entire width of web simultaneously, a drawback to a straight knife blade. To date, the highest web cutting speeds have been achieved with the combination of a rotary knife and helix shaped blade.

While rotary knives can achieve the highest cycle rates in the industry, they have been limited in their speed by the ratio of their circumference to the required product cut length. Knife speeds have to increase dramatically for any product length less than 75% of the knife blade circumference, which is the circumferential path traveled by the blade tip in one revolution of the knife. This has traditionally forced manufacturers to either add blades when cutting short products, cut double lengths and perform a secondary cutting process off-line, or slow web speed dramatically.

The prior art shows various attempts to cut shorter products using helical knives. It is known to run the knife at intermittent speeds: because the knife is running at a speed equivalent to web speed as the cut is made, it must be accelerated significantly and then slowed again in each cycle to shorten the cycle time to produce a shorter cut. This produces enormous torque variations in the knife and motor in every cycle.

In other words, for products whose lengths are less than the circumference of the knife blade, the knife must travel faster than web speed in order to make the proper cut length. Conventional knife design fixes the angle of the knife relative to the web such that at a synchronous cut speed, the knife will produce a straight cut. The requirement for a straight cut thus forces the knife drive system to

maintain a constant synchronous speed with the web while cutting. For shorter products where an overspeed is required, the knife must then overspeed and slow to web speed within each cut cycle.

For example, a knife with a circumference of 40" can rotate with a 1:1 relationship to the web if it is cutting a 40" product. The 1:1 relationship is referred to as synchronous. If the user wants to cut a 20" product, a length that is 1/2 the 40" circumference of the knife blade, then the knife must travel twice the distance, thus twice the speed of the web in order to make the proper cut length. Because the knife is required to travel at web speed while cutting in order to make a straight cut, the system must then slow from twice product speed to product speed when cutting. Thus, the drive system must, at the very least, double its speed and then halve its speed within each cut cycle. At high web speeds this situation quickly exceeds the torque capacity of the drive system.

SUMMARY OF THE INVENTION

The rotary knife described herein manipulates the angle of the knife cylinder relative to the web path to dramatically reduce the horsepower demands on the knife drive system for products that are shorter than the effective knife circumference and therefore increases the speed range of the rotary knife over a much broader range of product lengths.

The rotary knife concept allows the drive system to run at a continuous overspeed as required by the ratio of effective knife circumference to product length while manipulating the angle of attack of the knife in order to still achieve a straight cut. With no requirement to slow for cutting, the limitation on cut speed becomes top motor speed, not torque. This can represent as much as a 50% increase in speed or a 20% increase in product range for a given web speed.

The invention includes a method for cutting a moving web comprising adjusting the angle of a rotary knife with respect to web direction based on web speed, knife speed, and desired product length. This method allows the production of products with lengths shorter than the effective circumference of the rotary knife.

These and other features and advantages of the invention will become

apparent to those skilled in the art upon review of the following detailed description of the preferred embodiment of the invention, which is given by way of example only, reference being made to the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a schematic view of a web-cutting system embodying the invention.

Fig. 2 shows an overhead view of the web-cutting system illustrated in Fig. 1.

Fig. 3 shows an elevation view of the web-cutting system illustrated in Fig. 1.

Fig. 4 shows a cutaway view of a curved linear bearing taken along the IV-IV line of Fig. 2.

Fig. 5 shows a partial schematic view of the web-cutting system illustrated in Fig. 1.

Before one embodiment of the invention is explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangements of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or being carried out in various ways. Also, it is understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including" and "comprising" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 illustrates a web-cutting system for cutting a moving web of material such as paper. The web-cutting system is particularly suited for producing cut products shorter than the effective circumference of a rotary knife.

Figs. 1 and 2 illustrate the major components of the rotary knife cutting system 10. A machine base 98 supports the system 10. The system 10 includes a cutting unit 30 that includes a pivot end 32 and a free end 34. The substantially

rigid cutting unit 30 comprises five major components: a turret base 70, a speed reducer 38, a drive servo-motor 36, a pillow block assembly 60, and a knife cylinder 50.

The turret base 70 is mounted on the machine base 98 at two points. First, the turret base 70 is pivotally connected at the cutting unit pivot end 32 to the machine base 98 through a turret bearing 40 having a central axis 42. The turret bearing 40 allows the turret base 70 to rotate about the central axis 42 of the turret bearing 40. In alternate embodiments, any suitable system for supporting the cutting unit pivot end 32 to allow rotation in a horizontal plane can be used.

Second, the turret base 70 is translatably attached near the cutting unit free end 34 to the machine base 98 through a curved linear bearing 90. Figure 4 illustrates the details of the curved linear bearing 90. A car 94 of the curved linear bearing 90 is fixedly attached to the underside of the turret base 70. A rail 92 of the curved linear bearing 90 is attached to the machine base 98. The car 94 glides on the rail 92 to produce a translational motion. Thus, the curved linear bearing 90 allows the turret base 70 at the cutting unit free end 34 to move in an arcuately translational manner in either direction about the central axis 42 of the turret bearing 40.

As illustrated in Figure 2, two cars 94 are attached to the turret base 70 and glide on the rail 92 of the curved linear bearing 90. Rotation of the cutting unit pivot end 32 around the central axis 42 of the turret bearing 40 produces an arcuate translational movement of the cutting unit free end 34 along the rail 92 of the curved linear bearing 90. In alternate embodiments, any suitable system for supporting the cutting unit free end 34 to allow arcuate translational movement may be used.

In the preferred embodiment shown in Figs. 2 and 3, the arcuate translational movement of the cutting unit free end 34 is controlled by a translation servo-motor 80 that is pivotally connected at a translation servo-motor pivot end 84 to the machine base 98. The translation servo-motor 80 operates a connecting arm 82 that is pivotally connected to the turret base 70. The translation servo-motor 80 thus provides the motive force through the connecting arm 82 to effect the arcuate translational movement of the cutting unit free end 34

in either direction. In alternate embodiments, the arcuate translational movement of the cutting unit free end 34 may be effected by any other system including manual, mechanical, electrical, magnetic, or hydraulic systems.

In the preferred embodiment, the translation servo-motor 80 also provides through connecting arm 82 sufficient stability to lock the cutting unit free end 34 in place once the desired position of the turret base 70 and thus the cutting unit 30 has been achieved. In alternate embodiments, any suitable system for locking the cutting unit free end 34 in place can be used.

With the turret base 70 mounted on the turret bearing 40 on one end, and on the curved linear bearing 90 on the other end, the turret base 70 is free to move rotatably about the central axis 42 of turret bearing 40. All equipment mounted on the turret base 70 moves with the turret base 70.

A bed knife 72 is attached to the turret base 70.

The speed reducer 38 is mounted on the turret base 70 at the cutting unit pivot end 32, above the turret bearing 40, and rotates with the turret base 70 about the central axis 42 of the turret bearing 40. The speed reducer 38 is preferably a double-enveloping worm-gear speed reducer, but may be any other suitable type of speed. Fig. 2 also illustrates in phantom the internal gears of the speed reducer 38. The speed reducer 38 also includes a speed reducer output cylinder 39.

The drive servo-motor 36 is attached to a side of the speed reducer 38 and drives the speed reducer 38. Force from operating the drive servo-motor 36 operates the speed reducer 38 and subsequently turns the speed reducer output cylinder 39.

The pillow block assembly 60 is mounted on the turret base 70 at the cutting unit free end 34. The pillow block assembly 60 includes a cylindrical roller bearing 62 that is held within the pillow block assembly 60 with bolts 64.

The knife cylinder 50 has a first end 52 and a second end 54 and is rotatably mounted between the speed reducer output cylinder 39 and the pillow block assembly 60. The first end 52 of the knife cylinder 50 is pressure fit into the speed reducer output cylinder 39. No welds or bolts are used to secure the fit in this embodiment, but may be suitable in alternate embodiments. The second end 54 of the knife cylinder 50 is captured in the pillow block assembly 60 by the

cylindrical roller bearing 62 such that the knife cylinder 50 may rotate freely under the driving force provided by the drive servo-motor 36 through the speed reducer 38 and the speed reducer output cylinder 39. The knife cylinder 50 rotates about a knife cylinder axis of rotation 55. As shown in Figs. 1 and 2, a web 24 travels in a web direction 57. θ_K is the angle between the web direction 57 and the knife cylinder axis of rotation 55, and changes with the movement of the cutting unit 30. As the turret base 70 is moved as described above, the knife cylinder 50 automatically moved with the turret base 70 because they are components of the substantially rigid cutting unit 30. In Figure 2, θ_K is approximately 90 degrees.

In the preferred embodiment shown in Fig. 5, a helical blade 56 is attached to the knife cylinder 50 through a blade holder 58 that is mounted on the knife cylinder 50. The helical blade 56 subtends a total knife helix angle θ_T around the knife cylinder 50, where θ_T is approximately twenty degrees in the preferred embodiment. In alternate embodiments, θ_T may be any other suitable angle.

The blade holder 58 is mounted to the knife cylinder 50 using dowels and bolts. In alternate embodiments, any suitable method of attaching a helical blade to a knife cylinder can be used. In other alternate embodiments, additional helical blades 56 may be attached to the knife cylinder 50 as desired.

As shown in Fig. 5, the helical blade 56 on the knife cylinder 50 interacts with the bed knife 72 attached to the turret base 70 to perform a scissors-like cutting action. The cutting action can be used to cut a web 24 into a product or section 26.

In operation, as shown in Fig. 1, the rotary knife cutting system 10 is positioned between an infeed belt system 20 that feeds the web 24 to the rotary knife cutting system 10, and an exit belt system 22 that takes the product 26 from the rotary knife cutting system 10. Any suitable infeed and exit belt systems may be used.

More specifically, the web 24 is fed to the rotary knife cutting system 10 by the infeed belt system 20. The web 24 is fed through a gap between the helical blade 56 on the knife cylinder 50 and the bed knife 72 on the turret base 70. As the knife cylinder 50 and thus the helical blade 56 rotate about their longitudinal axis 55 at high speeds, the helical blade 56 interacts in a scissors-like action with

the bed knife 72 to cut the web 24 and produce the product 26. The product 26 is then carried away by the exit belt system 22. The web 24 continues to move in direction 57, the knife cylinder 50 continues to rotate, and the process repeats itself.

For example, in baseline operation, the desired product length is equivalent to the effective blade circumference, which is the circumferential distance traveled by the tip of the helical blade 56 during one rotation of the knife cylinder 50. In this case, because the desired product length is equivalent to the effective blade circumference, the knife cylinder 50 can rotate at the same speed as the web 24 is traveling.

To produce a product 26 of a length shorter than the effective blade circumference, a cut must be made more frequently if the speed of the web 24 is held constant. Thus, the rotational speed of the knife cylinder 50 must be increased to greater than the speed of the web 24, a condition known as overspeed. Overspeed of the knife cylinder 50, however, will produce a cut of the web 24 that is not perpendicular to the direction of travel 57 of the web 24 unless the overspeed is compensated for in a manner other than adjusting the rotational speed of the knife cylinder 50, because the rotational speed of the knife cylinder 50 with respect to the web speed only affects the length of the product.

Compensation for overspeed is provided by varying the angle θ_K of the cutting unit 30 and thus the knife cylinder 50 with respect to the direction of travel 57 of the web 24. The necessary angle of the cutting unit 30 is calculated as described below. In summary, a given web speed and the desired product length, along with a known effective circumference of the rotary knife, determine the necessary rotational overspeed of the knife cylinder 50. The necessary overspeed of the knife cylinder 50 is used to calculate the necessary angle of the cutting unit 30. Once the necessary angle of the cutting unit 30 is determined, the cutting unit free end 34 is moved in a arcuately translational manner about the central axis 42 of the turret bearing 40 in a horizontal plane until the necessary angle of the cutting unit 30 is achieved. The cutting unit 30 is then locked substantially in that position for the course of the web run. Product lengths shorter than the effective knife circumference can then be produced without a reduction in web speed.

The angle of the cutting cylinder necessary to produce a straight cut at a given product length, web speed, and knife cylinder rotational speed is calculated as follows:

Given:

θ_T = total knife helix angle (i.e., the angle of the knife cylinder 50 subtended by the helical blade 56)

θ_K = angle between the knife cylinder axis of rotation 55 and the web direction 57

W_W = web width

W_K = knife cylinder width

ω = angular velocity of the knife cylinder

r = knife radius

V_T = instantaneous knife tip velocity

V_W = web velocity

Set V_T such that $V_T > V_W$; set θ_K to 90 degrees.

Determine angle due to overspeed (θ_{OS}) that must be compensated:

Time for cut = $(1/\omega)(\theta_T/360)$

so: $\tan \theta_{OS} = (r\omega - V_W)/(W_W/((1/\omega)(\theta_T/360)))$

and $\theta_{OS} = \tan^{-1}((r-V_W/\omega)(\theta_T/360)/W_W)$

But one must also account for the total knife helix angle (θ_T) and the angle of the knife cylinder to the web (θ_K), which is adjustable. To compensate for θ_{OS}, the three angles (θ_{OS}, θ_T, and θ_K) should balance to zero, with direction of rotation considered:

$$\theta_{OS} - \theta_T + \theta_K = 0$$

thus: $\theta_K = \theta_T - \theta_{OS}$

and $\theta_K = \theta_T - \tan^{-1}((r-V_W/\omega)(\theta_T/360)/W_W)$

The angle of the knife cylinder 50 relative to the direction of the web travel 57 necessary to compensate for the knife cylinder overspeed can thus be calculated from quantities known to the web operator: the total knife helix angle, the knife radius, the web velocity, the angular velocity of the knife cylinder, and the web width.

While a preferred embodiment of the invention has been disclosed by way of example, various obvious modifications will become apparent to those skilled in the art. Thus, the scope of the invention should be limited only by the spirit and scope of the following claims.

I claim:

1. A method for cutting an endless web moving in a direction of travel at a predetermined speed into segments of equal length, the method comprising:

providing a rotary knife having an effective circumference and an axis of rotation which is adjustable relative to the direction of travel of the moving web;

calculating a knife angle to produce a cut extending perpendicular to the direction of web travel to produce a segment of predetermined length;

adjusting the position of the rotary knife with respect to the web such that the angle of the axis of rotation of the rotary knife relative to a line perpendicular to the direction of travel is equal to the knife angle; and

operating the rotary knife to cut the moving web.

2. The method of claim 1 wherein the calculating act includes calculating the rotational speed of the rotary knife based in part on the effective circumference of the rotary knife and the web speed.

3. The method of claim 2 wherein the calculating act includes calculating the knife angle based on the segment length.

4. The method of claim 1 wherein the rotary knife has a tip and wherein the effective circumference of the rotary knife is the distance traveled by the tip in one rotation of the rotary knife.

5. A method for cutting a moving web into sections having a length, the method comprising:

moving the web at a substantially constant web speed in a substantially constant direction of travel;

providing a knife cylinder set at a first knife angle with respect to the direction of web travel;

operating the knife cylinder at a first substantially constant rotational speed, wherein the first rotational speed is greater than the web speed; and

cutting the web to produce sections of a predetermined uniform length along a line substantially perpendicular to the direction of web travel.

6. The method of claim 5 wherein the providing step includes calculating the knife rotational speed based on the length of the sections to be cut.

7. The method of claim 5, wherein the providing step includes calculating the knife angle based on the length of the sections to be cut and the knife rotational speed.

8. The method of claim 5, wherein the length of the sections to be cut is less than the effective circumference of the rotary knife, wherein the rotary knife has a tip, and wherein the effective circumference of the rotary knife is the distance traveled by the tip in one rotation of the rotary knife.

9. The method of claim 5 further including the act of setting the knife angle at a second angle; operating the knife cylinder at a second substantially constant rotational speed greater than the web speed; and cutting the web to produce sections of a second predetermined, uniform length different from the first length.

10. The method of claim 9, wherein the second length is less than an effective circumference of the rotary knife, wherein the rotary knife has a tip, and wherein the effective circumference of the rotary knife is the distance traveled by the tip in one rotation of the rotary knife.

11. A rotary knife apparatus for cutting a moving web having a direction of travel and a speed into sections, the apparatus comprising:

a rotary knife having a rotational speed, a first end, and a second end, the first end being pivotably anchored and having a pivot axis, the second end being translatably anchored such that the rotary knife may pivot about the axis, the rotary knife defining a knife angle with respect to the direction of travel of the web, wherein the rotary knife and thus the knife angle can be adjusted to cut the web into sections of substantially identical lengths based on a combination of web speed, knife rotational speed, and section length.

12. The apparatus of claim 11 wherein the rotary knife includes a helical blade.

13. The apparatus of claim 11 wherein the rotational speed is variable and calculated based, in part, on web speed and section length.

14. The apparatus of claim 11 wherein the knife angle is adjustable and calculated based, in part, on web speed and rotational speed.

15. The apparatus of claim 11 wherein the sections are substantially rectangular.

16. The apparatus of claim 11 wherein the section length is less than an effective circumference of the rotary knife, wherein the rotary knife has a tip, and wherein the effective circumference of the rotary knife is the distance traveled by the tip in one rotation of the rotary knife.

17. The apparatus of claim 11 wherein the web speed and the rotational speed are substantially constant for a given section length, and the rotational speed of the knife is greater than the web speed.

18. A rotary knife cutting system mounted on a machine base, the system comprising:

a turret base having first and second ends, the first end being pivotably mounted on the machine base, the second end being translatably mounted on the machine base, the turret base including a bed knife;

a drive servo-motor mounted on the first end of the turret base;

a speed reducer drivingly connected to the servo-motor, the reducer including a speed reducer output cylinder;

a pillow block assembly mounted on the second end of the turret base and spaced apart from the reducer;

a knife cylinder rotatably mounted between the speed reducer output cylinder and the pillow block assembly;

a helical blade attached to the knife cylinder such that rotation of the knife cylinder results in a scissors-like interaction between the helical blade and the bed knife; and

an adjustable connecting arm attached between the machine base and the turret base to fix the position of the turret base with respect to the machine base.

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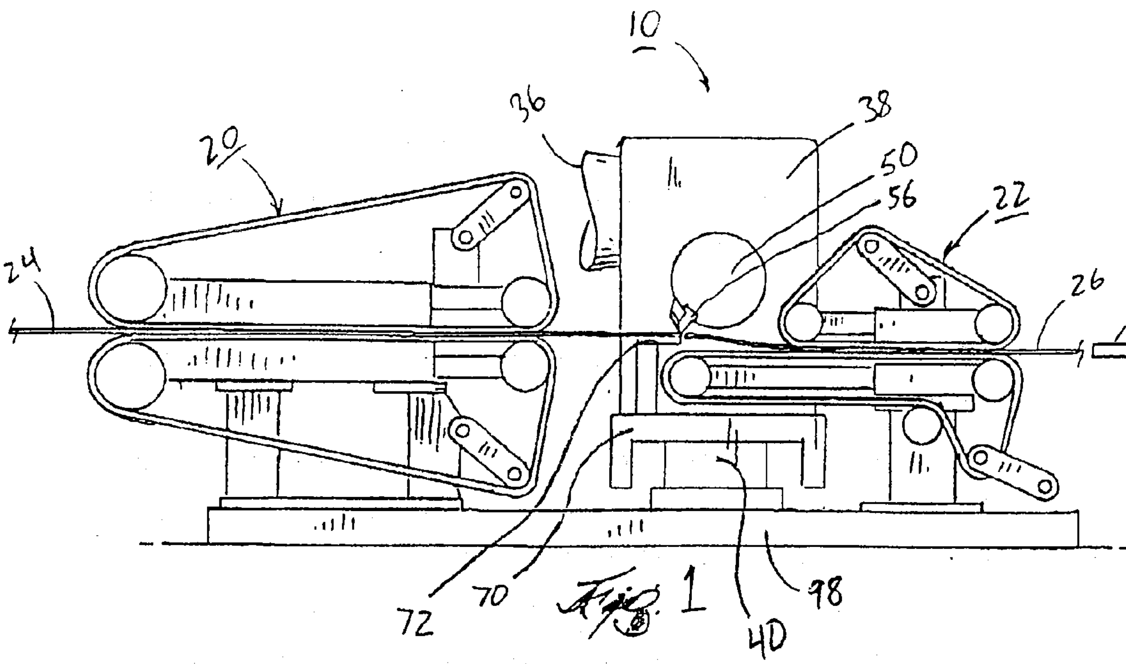

Fig. 1

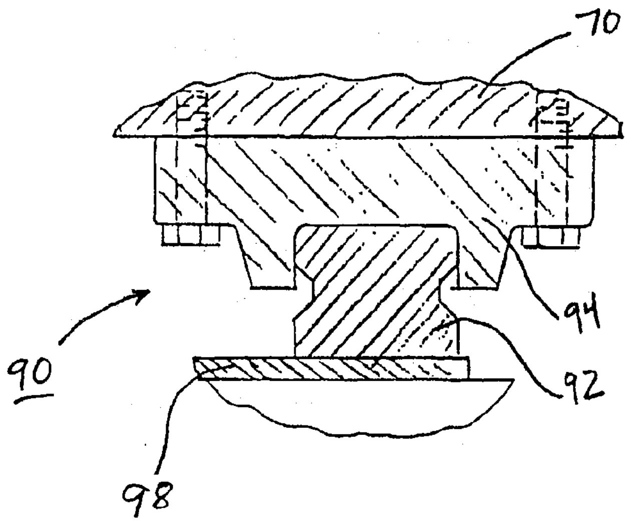

Fig. 4

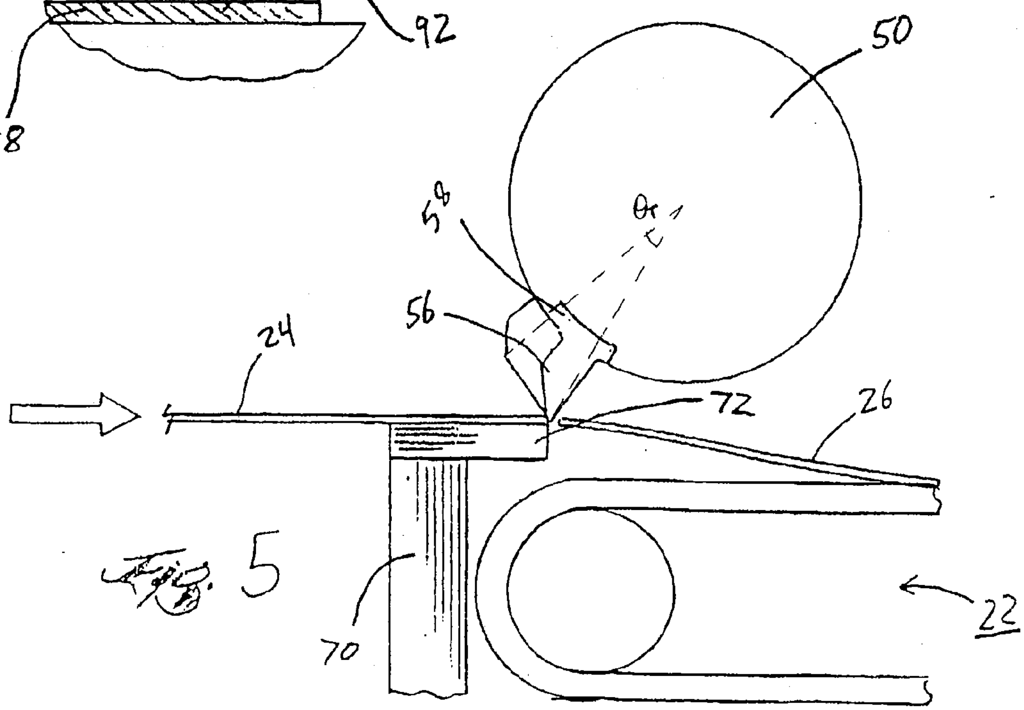

Fig. 5

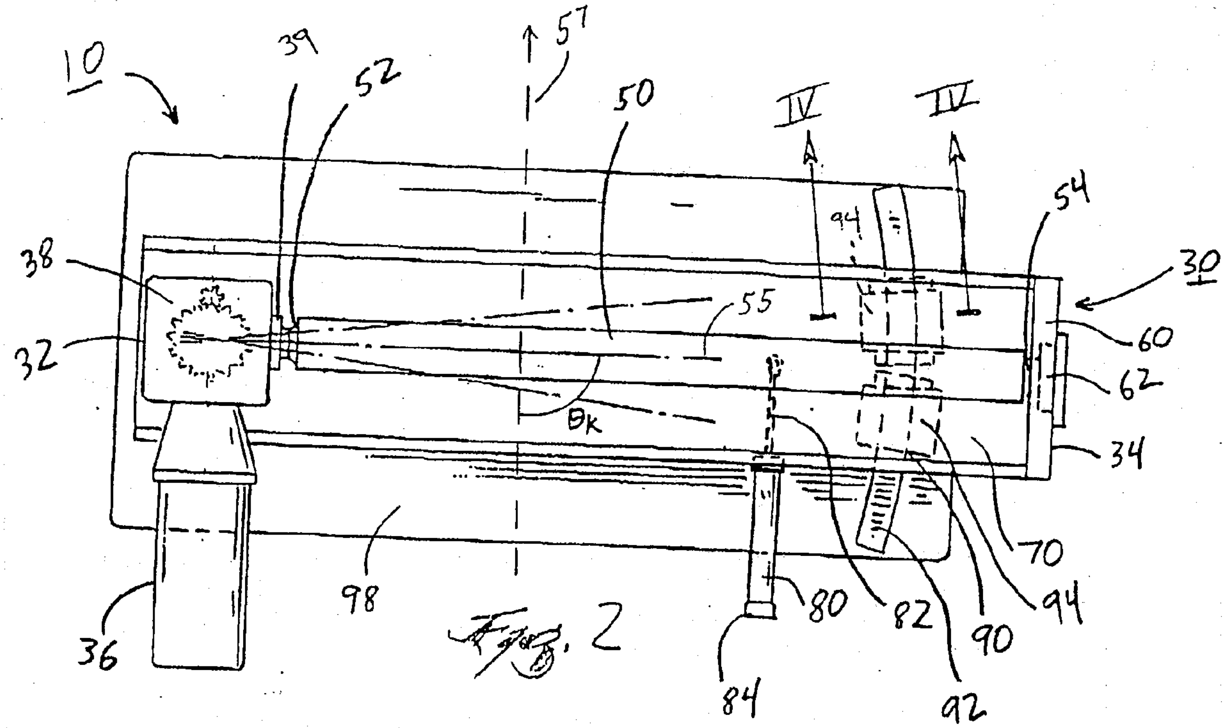
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Fig. 2

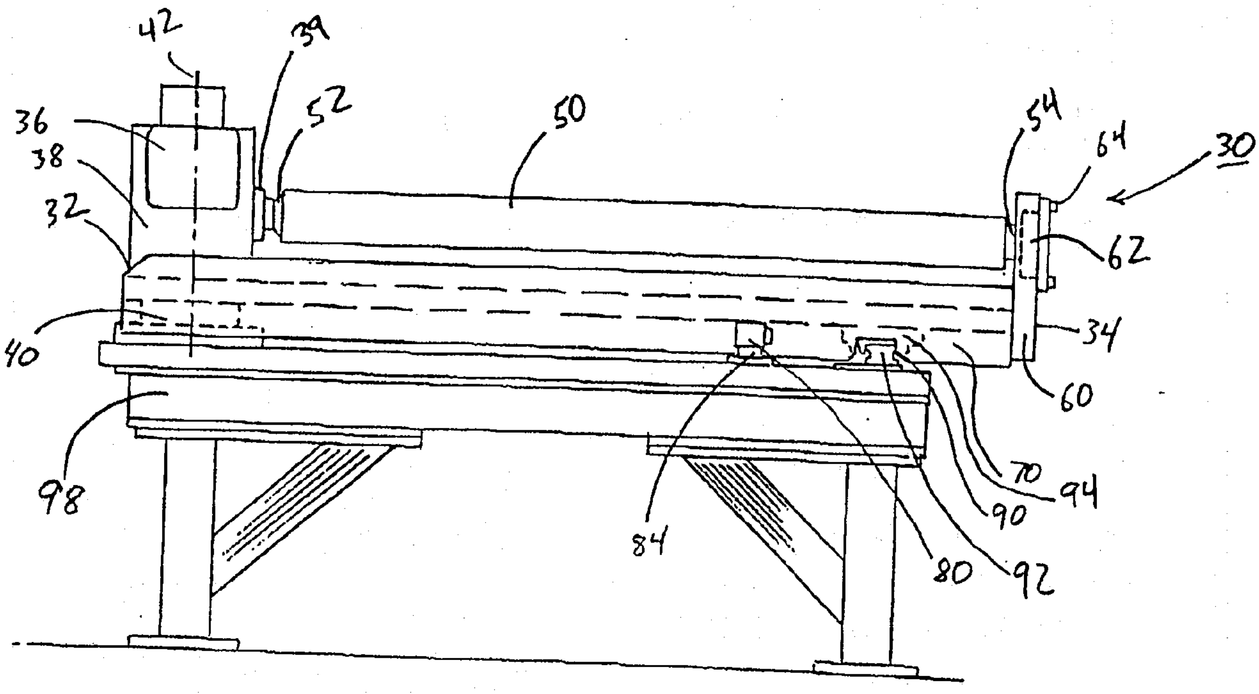
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Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/09294

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :B23D 25/02
US CL : 83/37, 38, 311

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 83/37, 38, 311, 312, 324, 334, 335, 340, 698.51

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST: rotary cutter

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3,552,251 A (NEFF et al.) 05 January 1971, col. 1, line 56; col 2, line 53; col 4, line 5; See entire document.	1-6, 11-17
A	US 3,190,163 A (BRADLEY) 22 June 1965, see entire document.	All
A	US 3,485,128 A (SIEGENTHALER) 23 December 1969, see entire document.	All
A	US 4,266,112 A (NIEDERMEYER) 05 May 1981, see entire document.	All
A	US 5,421,227 A (ROHRDANZ et al.) 06 June 1995, see entire document.	All

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

02 JUNE 2000

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